Research Paper:
Identification and Mapping of Environmentally Sensitive Areas of the Coastal Strip of Guilan Province

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ABSTRACT

Background: Oil spills caused by releasing liquid petroleum can spread on the coastal strip and affect coastal ecosystems, causing severe damage to the coastline environment and crisis in local communities. This study aimed to identify and map the environmentally sensitive areas of the coastal strip of Guilan Province, Iran, to oil spills using the Environmental Sensitivity Index (ESI).

Methods: The data required for the present study were collected through field studies, the GPS device, topographic maps of 1.25000 of the National Mapping Organization, maps of protected areas of the Environmental Protection Organization, satellite images, data of Guilan Province Industry, Mine and Trade Organization, and other relevant agencies. NOAA (National Oceanic and Atmospheric Administration) method and ESI were used to determine the sensitivity of the coastal strip of Guilan Province to oil spills. Moreover, to determine the weights of the criteria studied in the NOAA method, the analytic hierarchy process was used.

Results: The final results of the study of the environmental sensitivity of the coastal strip of Guilan Province to oil spills showed that 21.15%, 39.66%, and 39.19% of the coastal strip have low, medium, and high sensitivity, respectively.

Conclusion: High sensitivity mainly was related to the eastern part of the coast, located at the banks of estuaries of current rivers. Low sensitivity was also located along the seafront on fine- to medium-grained sand beaches, where less damaged in the event of oil spill pollution.

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1. Introduction

A coastal zone is an interface between the land and water and the common denominator of two ecosystems with distinct characteristics. The coastal environment is an evolved natural system, including the most complex and rich productive ecosystems on Earth. This zone is a transitional and vulnerable region and the last acceptor of land and sea pollutants exposed to pollutants accumulation and their potential threats [1]. The coasts have sensitive habitats and aquatic resources, mineral resources, and considerable recreation. They support for livelihood activities of fisheries and transportation industries [2].

Coastal zones are ecologically vital areas [3] affected by human activities. Therefore, the management and protection of the coastal environment, including sensitive ecosystems and rich in different biological species, is a complex challenge [4].

Oil spill pollution is an important environmental issue that can destroy marine and coastal ecosystems. It is scientifically proven that oil spills can profoundly affect coral reefs, marine mammals, fish, birds, marine plants, and coastlines [5, 6]. The first significant offshore oil spill occurred in 1907 when the TW Lowson tanker sank, releasing 7400 tonnes of petroleum off the England coast [7]. To respond systematically and quickly to such events, humans must acquire knowledge about coastal environments and management and prevention tools [8].

One of the management tools is using the Environmental Sensitivity Index (ESI) to determine the sensitivity of coastal stripes to oil spills, which was proposed in the 1970s [9]. The ESI was provided by the US National Oceanic and Atmospheric Administration (NOAA). This index presents the status of coastal resources that are at high risk during oil spills [10].

The term was first provided in the 1976s as the "coastal vulnerability index of oil spills based on the physical and biological factors of the coastline" [11]. It has emerged rapidly in recent decades due to the development of the Geographic Information System (GIS), multivariate analysis, and Remote Sensing (RS) techniques [12, 13]. Many researchers have realized this practical necessity and evaluated and ranked the sensitivity of coasts to oil spills. Rustandi et al. [14], on the southern coast of the Sumatera Province, developed an environmental sensitivity map as a strategy to prevent oil spills. Using ESI and spatial analysis in the GIS software environment, they obtained the final sensitivity map.

Abou Samra et al. [15] used the ESI to assess the Nile Coastal strip against potential oil spills. The Nile Delta is very close to the Suez Canal and is one of the main oil transportation routes in the world. Hernawan and Risdianto [16] used the ESI to manage potential oil spills in the oil and gas production block of Indonesia's central Kalimantan province. Research data were obtained through field survey and satellite imagery and analyzed in GIS software. The study data were obtained through field survey and satellite imagery and analyzed in the GIS environment.

Iran has no oil or gas extraction in the Caspian Sea, but the direction of water flow of the lake is from northwest to southeast, so the flow and high depth of water in the coasts of Iran slows down the flow of water, which leads to the accumulation of various pollutants, especially oil pollution. In recent years, various news sources have reported oil pollution in the coastal strip of Guilan Province [17]. Given the clockwise direction of surface currents in the South Caspian Sea and at the same time the general movement of water from the northwest to the south coast and from the southeast to the north [18], it is evident that the pollution of oil fields in Azerbaijan will spread into Guilan coasts. Therefore, this study aimed to identify and map the environmentally sensitive areas of the coastal strip of Guilan Province to oil spills using the ESI.

2. Materials and Methods

Study area

The study area was the coastal strip of Guilan Province in the South Caspian Sea with a length of 271 km from Astara to Chabaksar, located between the eastern Longitude 314173 to 464731 the northern Latitude 4090712 to 4256905 according to the Universal Transverse Mercator (UTM) system.

Study methods

In this study, to determine the sensitivity of the coastal strip of Guilan Province to oil spills, the NOAA method was used. According to this method, the ESI is a systematic approach to collect data in standard formats, including 1- coastal strip sensitivity, 2- biological resources, and 3- human resources, which also have subcategories. Remote sensing studies (using satellite images), field studies, available scientific resources, and available data and maps were used to collect the data in these formats.

All the collected data and mapping items are provided. To determine the coastal strip sensitivity (physical ranking), two methods of remote sensing and field studies were used. Landsat 8 satellite imagery was used in the remote sensing section. The study area is covered by four images taken from the website of the United States Geological Survey at http://glovis.usgs.gov/. Geometric correction of images was performed using maps of 1.25000 of the National Mapping Organization. Atmospheric correction was performed using a software tool for atmospheric correction. Then mosaic images were provided, and a single image was obtained. First, it was required to prepare a fake color scheme. The optimum index factor index was used for this purpose. Then, linear contrasts based on an extension were applied to the fake color image for greater clarity of effects. The Modified Normalized Difference Water Index (MNDWI) was used to determine the river banks [15], and the confluence coordinates of all rivers leading to the Caspian Sea were extracted.

To identify lake and estuary coasts based on the distinction between different sediments and coastal habitats in terms of the amount of penetration, impact, and stability of oil spills and ease of cleaning up and recovery, field studies and recording of points by the GPS were used, and the data were classified in Excel software. The mapping process was performed by entering the data into the ArcGIS software environment. The coastline rankings included ten main rankings, and each rank was subdivided into sub-ranks. Coasts with lower numerical rankings have lower sensitivity due to resistance to oil penetration and stability, and on ease of oil spills clean up. In other words, from rank 1 to rank 10, the sensitivity of the rankings increases [10].

To identify biological resources, a Guide to the Birds of IRAN [19] for birds, an atlas of invertebrates of the Caspian Sea [20] for invertebrates, Water Plants book [21], and other research studies were used. The collected data of biological resources were listed by species code in the ESI, then each group was given a code, and their locations were determined on the coastal strip. To identify the resources used by humans, the data of Guilan Province Industry, Mine and Trade Organization, General Directorate of Fisheries, and General Directorate of Ports and Maritime Affairs were used and completed by field studies.

Human resources contain three groups: recreation-access, areas under management, and exploitation of resources and reserves. After determining each of the resources used by humans, the base location and the sensitivity were determined according to the NOAA guidelines. To determine the weights of the three criteria according to the sub-criteria of each criterion, the Analytic Hierarchy Process (AHP) was used. After preparing the relevant questionnaire, 12 questionnaires were distributed among environmentalists in the field of coastal pollution, and the geometric mean of the completed questionnaires was analyzed. Each questionnaire included a table to express the linguistic scale of the importance of criteria and sub-criteria in relation to each other and several pairwise comparison matrices of criteria and sub-criteria. Then the AHP was performed in the AHP calculator online. The weights of each criterion and sub-criteria were calculated, and by multiplying the relative weights together, the final weights of the three criteria were obtained. Finally, the obtained maps for each of the three criteria were weighed and integrated by the weighted sum function in the ArcGIS software environment, and the final map of the ESI was obtained.

3. Results and Discussion

Determining the sensitivity of the coastal strip to oil spills based on the NOAA method

Physical classification of the coastal strip

The coastal strip of Guilan Province was classified into low, medium, and high sensitivity categories based on the top ten ranks of the NOAA method (Figure 1). The coasts with lower numerical values due to their resistance to oil penetration and stability, and the ease of cleaning up oil spills have lower sensitivity. The results of the physical classification of the coastal strip showed that the eastern and central parts of the coast have higher sensitivity. Low and medium sensitivity zones were identified along the coastline, and high sensitivity zones were identified along the estuaries of current rivers. Given that the estuarine areas of the current rivers, due to their physical ability and bed material, can maintain and sustain oil pollution for a longer period of time, and their cleaning up and recovery speed is slower. So, in the case of oil spill pollution and its spread to these areas, they suffer the highest damage [10].

Biological resources

Identified biological species sensitive to potential oil spills were divided into five groups according to the ESI, including birds, invertebrates, reptiles/amphibians, plants/algae, and marine mammals (From the mammal's group, just the *Phoca caspica*). Local fishermen reported it during the spring and summer seasons. The bird group has a high diversity in the study area, and 26 bird spe-

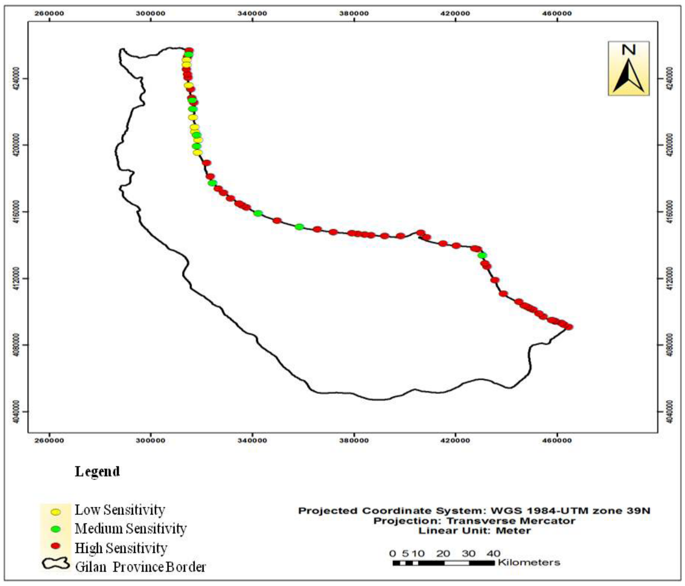

Figure 1. Physical classification of the coastal strip

cies from 6 subgroups were identified in the coastal area. From the subgroup of Larus and Sternidae with eight species, such as *Larus ridibundus* and Larus *minutus*, and also from the subgroup of coastal birds with six species, *Phalaropus lobatus* and *Actitis hypoleucos* can be mentioned. According to the results, the diversity of birds in the central areas of the coastline was higher. From the group of reptiles, *Natrix natrix* was identified. Invertebrates identified in the coastal area included 14 species, genera, and families, including Tridentat *Rhithropanopeus harrisii*, *Palaemon elegans* Rathke, *Nereis* spp., Gammaridae family, and Amphibalanus improvises. A group of water plants was observed in estuaries of current rivers, such as *Phragmites australis* and *Typha* spp. and another group of plants, such as *Cakile maritima* and *Convolvulus persicus*, were identified in coastal areas.

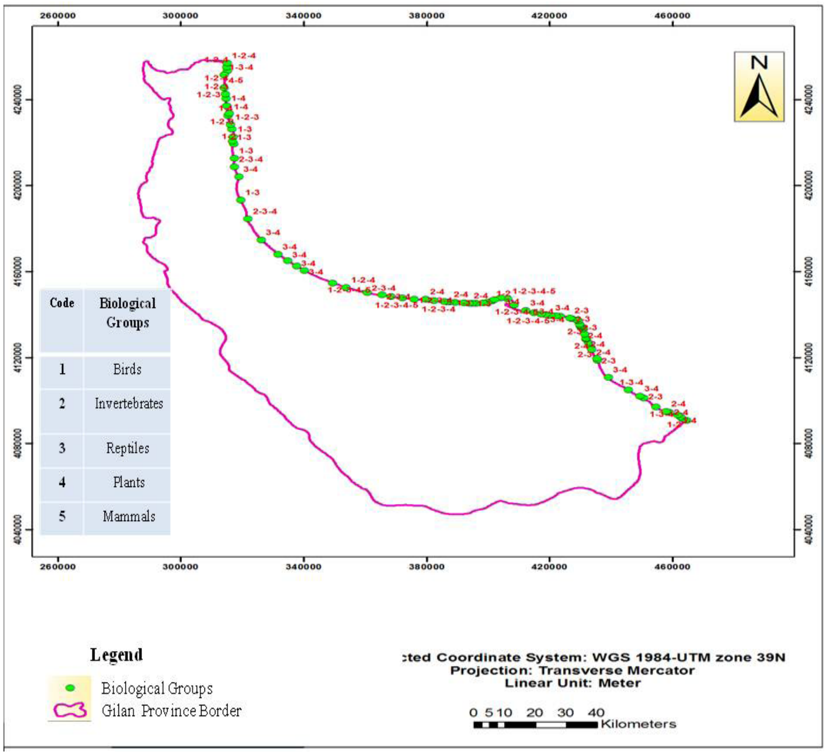

Figure 2. The map of the biological groups locations on the coastline

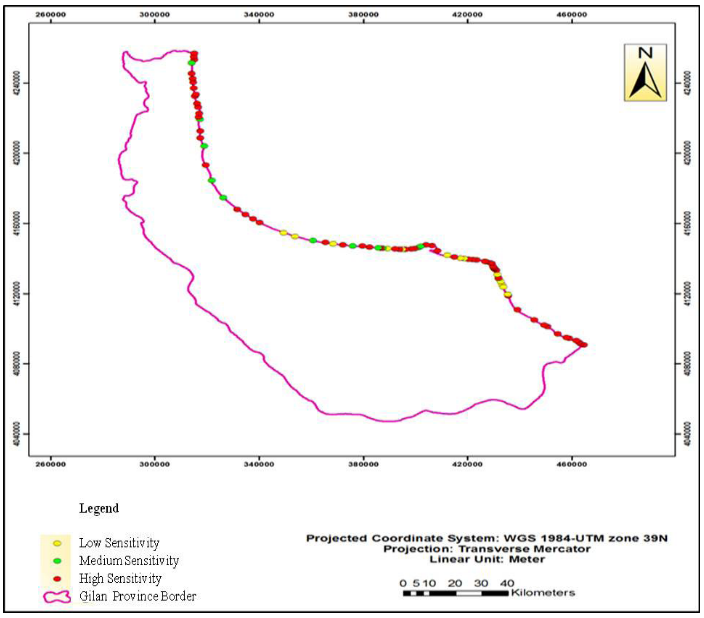

Figure 3. Map of resources used by humans in terms of sensitivity to oil spills

The identified algae included *Enteromorpha intestinalis* and *Laurencia caspica*. The collected data regarding biological resources for birds, invertebrates, reptiles-amphibians, plants-algae, and mammals were separately listed by species code in the ESI, and each group was given a code, and their locations were identified on the coastal strip (Figure 2). Figure 3 reveals that in the central area of the coastline, the biological groups and species diversity are much higher than in other parts; therefore, special attention must be paid to this area.

Resources used by humans

After determining each of the resources used by humans, the base location and the sensitivity were determined according to the NOAA guidelines. Figure 4 shows a map of the three categories of the low, medium, and high sensitivity for resources used by humans along the coastline. The map of human resources in terms of sensitivity to oil spills (Figure 3) showed that sensitive points are scattered almost along the entire coast. Therefore, it is crucial to adapt human uses and activities to the capabilities and sensitivities of the region. It is worth mentioning that in the western area and at the end of the coastline, the sensitivity to oil spills is high in terms of human resources. Field studies, as well as using satellite images, revealed that there are many agricultural lands in this area. As a result, their effluent discharge has increased and has had a significant impact on determining sensitivity.

Determining the weights of NOAA criteria and preparing the final map of the coastal strip sensitivity to oil spills

After performing the hierarchical analysis method in the online AHP calculator and estimating the weight of each criterion and sub-criteria (Tables 1, 2, and 3) and also by multiplying the relative weights together, the final weight of the three criteria was obtained.

Finally, the obtained maps for each of the three criteria were weighted and integrated into the ArcGIS software

Table 1. Weight of coastal strip physical classification sub-criteria

(-)	(+)	Rank	Priority	Category	Number
6.5%	6.5%	2	22.6%	Estuarine	1
2.9%	2.9%	3	10.1%	Lacustrine	2
19.5%	19.5%	1	67.4%	Riverine	3
Consistency Ratio (CR)=9.0%					

Table 2. Weight of biological resources sub-criteria

(-)	(+)	Rank	Priority	Category	Number
7.2%	7.2%	2	50.29%	Birds	1
2.3%	2.3%	3	9.6%	Invertebrates	2
2.4%	2.4%	4	9.3%	Reptiles	3
1.6%	1.6%	5	4.6%	Plants	4
10.2%	10.2%	1	47.0%	Mammals	5
Consistency Ratio (CR)=3.1%					

environment, and the final map of the ESI was obtained (Figure 4). The share percentage of different parts of the Guilan coastal strip from different categories of sensitivity to oil spills is presented in Table 4.

The coastal-marine environment, due to its close interaction with the atmosphere, land, and inland waters, plays a pivotal role in the biosphere functions and is considered as the main living and non-living resources, each of which has obvious and undeniable effects on the social and economic life of countries. Several researchers, such as Grimaldi et al. [22], Mityagina and Lavrova [23], and Holstein et al. [24] have reported oil spills in the Caspian Sea. In recent years, various news sources have also reported oil spill pollution in the coastal strip of Guilan Province [13].

The main issue in protecting the coast from oil spill pollution is preventing the occurrence or being prepared to make scientific and informed decisions to manage the crisis and minimize its resulting damages. To this end, it is necessary first to identify fully the coastline regarding sensitivity to oil spill pollution. Therefore, the present study aimed to achieve this vital issue. The NOAA method was used to determine the sensitivity of the coastal strip of Guilan province to oil spills, and remote sensing and field studies were used to collect the data. The MNDWI was used by Landsat 8 satellite images to extract locations of rivers leading to the sea and to identify river banks. Other researchers have also identified water resources using Landsat 8 satellite data and by implementing this [24-26].

Based on the results of the physical classification section, out of 56 identified rivers leading to the sea in the study area, most of them are located in the eastern and central parts. Considering the ranks of estuarine areas of the rivers obtained in the ESI of NOAA method and their physical ability and bed material, they can maintain and sustain oil pollution for a longer period of time, clean up, and recovery speed is slower. Therefore, in the case of oil spill pollution and its spread to these areas, they suffer the highest damage.

According to the biodiversity identified on the coasts of Guilan, in the event of oil spill pollution, it will have many adverse effects on these water-dependent resources. One of the valuable species of the Caspian Sea is *Phoca caspica*, and scientific studies have shown that this species suffers from various complications under the influence of oil, including hypothermia in infants due to reduced fur cover [27]. Given the suitable diversity

Table 3. Weight of sub-criteria of resources used by humans

(-)	(+)	Rank	Priority	Category	Number
2.7%	2.7%	3	9.4%	Recreation/access	1
18.1%	18.1%	1	62.7%	Areas under management	2
8.1%	8.1%	2	28.0%	Exploitation of resources and reserves	3
Consistency Ratio (CR)=8.9%					

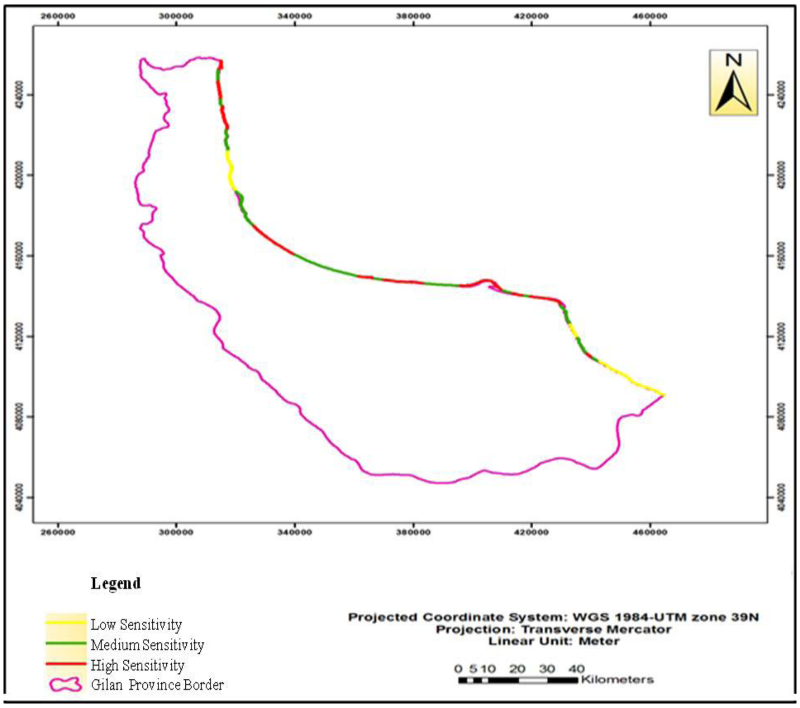

Figure 4. Final map of the coastal strip environmental sensitivity to oil spills

of bird species in the study area, including *Larus ridibundus*, *Larus minutus*, *Phalaropus lobatus*, and *Actitis hypoleucos*, in the event of oil spills, their feathers will become hypothermic due to the loss of their insulating and waterproof properties, and they lose their ability to float due to oil-soaked feathers and weight gain [25].The identified invertebrates are also at risk [26]. Petroleum derivatives remaining in sediments have harmful effects on nutrition, growth, and life of invertebrates identified in the study area, including Rhithropanopeus harrisii tridentat and increase toxicity in polychaetes, reduce the growth rate in shrimp, cause the uptake of petroleum products by barnacles [28, 29].

Regarding resources used by humans, another effective factor was recreation/access. Because the coasts of Guilan Province have many tourist attractions, the distribution of sensitivity points to oil spills in terms of resources used by humans is along the entire coastline. In Bandar Anzali City, there are 38 marine tourism wharves (recreational/sailing). Therefore, identifying areas sensitive to oil spills is important since too much investment has been made in these sectors, and by decreasing tourist numbers, a lot of financial losses will occur in these tourist places. Moreover, in the field of resources used by humans, recreational fishing areas are of great importance. The most important of which in the province include Sefidrood Bridge in Astane Ashrafieh City, Breakwater in Bandar-e Anzali, and Kiashahr fishing port. All of the mentioned areas are very important in determining the sensitivity of the coastline to oil spills; therefore, it is essential to pay attention to them.

The final results related to the environmental sensitivity of the coastline to oil spills showed that 21.15%, 39.66%, and 39.19% of the coastline are related to low, medium, and high sensitivity, respectively. Sepehr et al. in a study on the east coast of Guilan Province, reported 69%, 12%, and 19% for low, medium, and high sensitivity categories, respectively [30]. Regarding this differ-

Table 4. Percentage of sensitivity categories in coastal strip Guilan Province to oil spills

Equivalent Length (km)	Percentage	Degree of Sensitivity
57.37	21.15	Low
107.48	39.66	Medium
106.20	39.19	Much

ence, it should be mentioned that in the present study, the highest value of the east coast length (about 36 km) is related to the low sensitivity category, and if only the east coast area is considered for the study, the results of Sepehr et al. study are consistent with the present study. Despite the slight differences between the two studies, their research was conducted in 2014, so during this period, some locations or types of economic activities in the coastal strip have changed. Based on the study on insensitive areas, Hernawan et al. [31] reported 12.8%, 31.9%, 14.6%, and 40.7% for low, medium, and high sensitivity categories, respectively. They showed that the river bank adjacent to the oil and gas block of Kalimantan Province, Indonesia, similar to the coastal strip of Guilan, allocates a large percentage to the high-sensitivity category.

Habibi et al. also conducted a study on the environmental sensitivity of the coastal strip of Hormozgan Province, Iran, and like the present study, they reached a high number (28%) for the high-sensitivity class [32]. Saeb and Karami Rad conducted an environmental assessment of the coastal strip of Abbasabad City in relation to oil spills using the ESI and showed that 10% of the coastline is highly sensitive. Comparison of their research with the present study shows that the sensitivity of the coastline of Guilan Province is much higher, and it is necessary to pay special attention to policies and planning [2].

In the present study, low-sensitivity points were located along the seafront on fine- to medium-grained sand beaches. This type of coast is impermeable to oil spills due to its particle size and therefore has a low sensitivity to oil spills, and in case of oil spill pollution, this area will be less damaged. These results are also in line with the results of Fatemi et al. study [33]. They determined the environmental sensitivity of the coastal strip of Tonekabon to possible oil spills. They found that only the estuarine areas had high-sensitivity ranks; however, the lowest sensitivity was found in fine- to medium-grained sand beaches. This means that in the event of oil spills, these areas, due to intermittent seasonal storms, low sediment transport rate, and low permeability of the coast, have less environmental sensitivity and clean up naturally and more quickly.

The present study has some limitations as follows: lack of easy access to high-resolution satellite imagery to extract data and information required to use the ESI, an insufficient database for biological groups in the coastal strip, and insufficient information about economic activities in the coastal strip and also lack of information to the researcher.

It is suggested that changes in the physical structure of the shoreline be recorded in time series using the remote sensing technique, and it is also suggested that the ESI be calculated using learning machine models.

4. Conclusion

The results of the physical classification of the coastal strip showed that the eastern and central parts of the coast are more sensitive in terms of the amount of oil infiltration and its purification. Regarding this section's results, most of the identified rivers leading to the sea are located in the eastern and central parts, and the estuarine areas of the rivers are highly sensitive to the NOAA method. The results of the biological groups showed that in the central part of the coastline, there are most biological groups, and the species diversity is much higher than in other sections. Therefore, special attention to this section is essential. For example, in the case of an oil spill, for Phalaropus lobatus species with loss of insulating and waterproof properties, their feathers become hypothermic and lose their ability to float due to oil-soaked feathers and weight gain. The map of human resources used in terms of sensitivity to oil spills showed that sensitive points are scattered almost along the entire coast. Therefore, it is crucial to adapt human uses and activities to the strengths and sensitivities of the region. Another effective factor in this section was recreation, and because the coast of Guilan Province has many tourist attractions, so the distribution of sensitive points is along the entire coastline. For example, in Bandar Anzali City, there are 38 marine tourism wharves. Therefore, identifying sensitive areas to oil spills shows its importance because a lot of investment has been made in these sectors, and with the decrease of tourists, a lot of financial damage will be inflicted on these tourist places.

Ethical Considerations

Compliance with ethical guidelines

All ethical principles are considered in this article.

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Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

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